TITLE OF THE INVENTION

SIGNAL PROCESSING APPARATUS, IMAGE PROCESSING APPARATUS AND THEIR METHODS

5   BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a signal processing apparatus, image processing apparatus, and their methods and, for example, to a signal processing

10   apparatus, image processing apparatus, and their methods for converting or transforming (gamut-mapping) a signal in a given color space into that in another color space.

Description of Related Art

15   A computer system or video printer, which has a color monitor and color printer, a color image created and/or processed on a monitor, or a color image received by an image receiving device, is often printed out.

As is known, a color monitor that expresses a

20   color image by emitting light in a specific wavelength range using a phosphor has a quite different color gamut from that of a color printer that expresses a color image by absorbing light in a specific wavelength range using ink or the like, and using remaining reflected

25   light. Furthermore, color monitors have different color gamuts depending on their types, i.e., a monitor that

uses liquid crystal, a monitor using an electron gun type cathode ray tube, a monitor using a plasma system, and the like. Similarly, color printers have different color gamuts depending on different paper qualities,

5   different ink consumption amounts, and the like.

For this reason, it is impossible to colorimetrically match the colors of an image displayed on a given color monitor, an image output by a given color printer, and color images output using a plurality

10   of types of printers and a plurality of types of recording sheets. Hence, when a person sees color images displayed (formed) on individual output media, he or she experiences large tincture or color appearance differences among images.

15   Gamut mapping or color matching is known as an image processing technique for absorbing such perceptual tincture differences of displayed (formed) color images among output media having different color gamuts and perceptually matching their tinctures with each other.

20   According to one image processing technique, gamut mapping is done by computing the square sum of differences between color signals for all colors used in a color monitor and those used in a color printer, and minimizing the square sum. However, this technique can

25   obtain a satisfactory result within the color gamuts of the two devices, but considerably impair image

information for color signals falling outside the ranges

due to losses of grayscale characteristics or the like.

For this reason, when an image has color signals falling

outside the color gamuts of the two devices, it is

5   observed to have quite different colors when it is

displayed or formed by these devices.

Also, various gamut mapping techniques have been

developed under the condition that grayscale information

is preserved as much as possible, in consideration of

10   the aforementioned problem relating to tone reproduction.

However, in these techniques, since the amplitude of a

difference signal between a color signal of a color

monitor and that of a color printer upon expressing a

given color becomes large for all colors, images

15   displayed or formed by these devices are observed to

have considerably different colors.

In this manner, a gamut mapping technique that can

simultaneously solve these two problems is demanded.

As personal computers and workstations prevail,

20   desktop publishing (DTP) and computer-aided design

techniques are used in many occasions. In such situation,

a color reproduction technique that reproduces colors

expressed on a monitor by a computer using actual color

agents is important. For example, in case of DTP, a

25   color image is created, edited, processed, and so forth

on a color monitor, and is output via a color printer.

For this reason, it is strongly demanded that the colors
of an image displayed on the color monitor (to be
referred to as a "monitor image" hereinafter)
perceptually match those of the image printed out (to be

5   referred to as a "print image" hereinafter).

However, perceptual color matching between the
monitor and print images encounters difficulty for the
aforementioned reasons.

As a technique for absorbing perceptual color

10 differences among output media having different color
gamuts and perceptually matching the colors of images
formed, gamut mapping for mapping a given color gamut
into another color gamut is known. Gamut mapping
performs, e.g., linear mapping in the

15 lightness-saturation plane in units of hues in a uniform
colorimetric system. According to this technique, the
color gamut of a monitor shown in the graph of Fig. 19A
is mapped into the color gamut of a printer shown in the
graph of Fig. 19B.

20 However, as shown in Fig. 19B, the mapped color
gamut indicated by the solid curve is narrower than the
printer color gamut indicated by the one-dashed chain
curve. An image that has been corrected by such gamut
mapping and is printed out normally has low contrast and

25 poor vividness.

SUMMARY OF THE INVENTION

The present invention has been made to solve the aforementioned problems, and has as its object to provide a signal processing apparatus and method, which

5   can convert a color signal so that colors formed and/or displayed by different devices and/or different recording media are perceived as closely resembling colors.

It is another object of the present invention to

10 provide an image processing apparatus and method which can implement gamut mapping capable of obtaining a vivid output image with high contrast.

In order to achieve the above objects, a preferred embodiment of the present invention discloses an image

15 processing method for mapping an input color of an input color gamut to an output color of an output color gamut, the method comprising the steps of:

inputting an input color signal of the input color gamut, which includes a signal indicating brightness and

20 a signal indicating tincture; and

mapping the signal indicating brightness and the signal indicating tincture on the basis of the input and output color gamuts,

wherein the mapping maps the signal indicating

25 brightness using a mapping condition which is computed in accordance with highlight portions of the input and

output color gamuts, and increases a degree of mapping of the highlight portion compared to middle lightness.

A preferred embodiment of the present invention discloses an image processing apparatus for mapping an input color of an input color gamut to an output color of an output color gamut, comprising:

inputting means for inputting an input color signal of the input color gamut, which includes a signal indicating brightness and a signal indicating tincture; and

mapping means for mapping the signal indicating brightness and the signal indicating tincture on the basis of the input and output color gamuts,

wherein the mapping maps the signal indicating tincture using a mapping condition which is computed in accordance with high-saturation portions of the input and output color gamuts at a predetermined hue, and increases a degree of mapping of the high-saturation portion compared to a low-saturation portion.

It is still another object of the present invention to provide an image processing apparatus and method, which can satisfactorily absorb shape differences of the color gamuts of input and output devices, and can obtain a high-quality output image.

In order to achieve the above object, a preferred embodiment of the present invention discloses an image processing method for mapping an input color of an input color gamut to an output color of an output color gamut,

5 said method comprising the steps of:

executing a first mapping process for the input color gamut in accordance with the input and output color gamuts; and

executing a second mapping process for a mapped

10 color gamut obtained by the first mapping process in accordance with the mapped color gamut and output color gamut.

A preferred embodiment of the present invention discloses an image processing apparatus for mapping an

15 input color of an input color gamut to an output color of an output color gamut, comprising:

first mapping means for executing a first mapping process for the input color gamut in accordance with the input and output color gamuts; and

20 second mapping means for executing a second mapping process for a mapped color gamut obtained by the first mapping process in accordance with the mapped color gamut and output color gamut.

Other features and advantages of the present

25 invention will be apparent from the following description taken in conjunction with the accompanying drawings, in

which like reference characters designate the same or
similar parts throughout the figures thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

5   Fig. 1 is a block diagram showing the system
arrangement of a color signal conversion apparatus
according to the first embodiment of the present
invention;

       Fig. 2 is a block diagram showing the arrangement
10 of a color signal converter shown in Fig. 1;

       Fig. 3 is a graph showing the input/output
relationship of lightness in the first embodiment;

       Fig. 4 is a block diagram showing the arrangement
of a saturation compression unit shown in Fig. 2;

15   Fig. 5 is a graph showing the input/output
relationship of saturation in the first embodiment;

       Fig. 6 is a graph showing the lightness
compression input/output characteristics when gamut
mapping is done in correspondence with a plurality of

20 paper qualities;

       Fig. 7 is a graph showing the input/output
relationship of lightness in the second embodiment;

       Fig. 8 is a block diagram showing the arrangement
of a color signal converter according to the third

25 embodiment;

Figs. 9 and 10 are graphs showing the input/output relationship of lightness at given chromaticity ab;

Fig. 11 is a block diagram showing the arrangement of a color signal converter according to the fifth embodiment;

Fig. 12 is a block diagram showing the arrangement of a saturation compression unit shown in Fig. 11;

Fig. 13 is a flow chart showing the operation of a saturation computing section shown in Fig. 11;

Fig. 14 is a block diagram showing the arrangement of a color signal converter according to the sixth embodiment;

Fig. 15 is a block diagram showing the arrangement of a saturation compression unit shown in Fig. 14;

Fig. 16 is a block diagram showing the arrangement of a color signal converter according to the seventh embodiment;

Fig. 17 is a block diagram showing the arrangement of a saturation compression unit shown in Fig. 16;

Fig. 18 is a block diagram showing the arrangement of a color signal converter according to the eighth embodiment;

Figs. 19A and 19B are views for explaining gamut mapping;

Fig. 20 is a block diagram showing the arrangement of a color signal converter according to the ninth embodiment;

Figs. 21 to 23 are graphs for explaining gamut mapping in the ninth embodiment;

Fig. 24 is a flow chart showing mapping by a gamut enlargement correction unit shown in Fig. 20;

Fig. 25 is a graph for explaining mapping by the gamut enlargement correction unit;

Fig. 26 is a graph showing an example of an input/output function $f(\cdot)$ used by the algorithm of the gamut enlargement correction unit;

Fig. 27 is a graph showing the gamut mapping result by the gamut enlargement correction unit;

Fig. 28 is a block diagram showing the arrangement of a color signal converter according to the tenth embodiment;

Fig. 29 is a graph comparing monitor and printer gamuts;

Fig. 30 is a flow chart showing the operation algorithm of an upper-limit color reproductive range computing section shown in Fig. 28;

Fig. 31 is a graph showing a printer, monitor, and enlarged monitor gamuts;

Fig. 32 is a graph showing an example of an upper-limit color reproductive range computed by the upper-limit color reproductive range computing section;

Fig. 33 is a flow chart for explaining the operation of a gamut enlargement correction unit of the tenth embodiment;

Fig. 34 is a graph for explaining mapping by the gamut enlargement correction unit of the tenth embodiment;

Fig. 35 is a graph showing an example of an input/output function $f(\cdot)$ used by the algorithm of a gamut enlargement correction unit of the tenth embodiment;

Fig. 36 is a block diagram showing the arrangement of a color signal converter according to the eleventh embodiment;

Fig. 37 is a graph showing a first intermediate mapped gamut for green hues;

Fig. 38 is a graph showing a second intermediate mapped gamut for green hues;

Fig. 39 is a graph showing a mapped gamut for green hues;

Fig. 40 is a graph showing an example of the input/output function that implements nonlinear mapping of lightness components;

Fig. 41 is a flow chart showing mapping of saturation components by a gamut mapping unit 2207 in the eleventh embodiment;

Fig. 42 is a graph showing the spatial relationship between colors M and Bm;

Fig. 43 is a graph showing an example of a saturation input/output function $g(\cdot)$ that implements nonlinear mapping of saturation components;

Fig. 44 is a flow chart showing mapping of hue components by the gamut mapping unit 2207;

Fig. 45 is a graph showing an example of a hue input/output function $h(\cdot)$ that implements nonlinear mapping of hue components;

Fig. 46 is a flow chart showing the operation of a gamut mapping unit 2209;

Fig. 47 is a graph showing the spatial relationship among colors obtained in steps S1201 to S1206 shown in Fig. 46;

Figs. 48A and 48B are graphs showing examples of an input/output function $p(\cdot)$ that implements nonlinear mapping of lightness components;

Fig. 49 is a flow chart showing the operation of a gamut correction unit 2211;

Fig. 50 is a graph showing the spatial relationship among colors obtained in steps S2601 to S2604 shown in Fig. 49;

13

Figs. 51A and 51B are graphs showing examples of an input/output function $q(\cdot)$ that implements nonlinear mapping of saturation components; and

Fig. 52 is a graph showing monitor and printer gamuts for red hues.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of a signal processing apparatus, image processing apparatus, and their methods according to the present invention will be described in detail hereinafter with reference to the accompanying drawings.

First Embodiment

[System Arrangement]

Fig. 1 is a block diagram showing the system arrangement of a color signal conversion apparatus according to the first embodiment of the present invention.

Referring to Fig. 1, reference numeral 201 denotes a microprocessor (CPU); 202, a main memory comprising a RAM or the like; 203, a Small Computer Standard Interface (SCSI) card; 204, a network interface card (NIC); 205, a hard disk drive (HDD); 206, a graphic accelerator card; 207, a color monitor such as a CRT, LCD, or the like; 208, a color signal converter with a parallel interface such as Centronics for connecting a

printer; 209, a color printer; 210, a keyboard/mouse controller; 211, a keyboard; 212, a pointing device such as a mouse or the like; 213, a local area network (LAN); and 214, a Peripheral Component Interconnect (PCI) bus.

5   Note that the CPU 201 implements various processes (to be described later) in accordance with an Operating System (OS), image processing program, and data stored in a ROM 215 and/or the HDD 205.

In the above arrangement, image data stored in the
10 HDD 205 is transferred to the main memory 202 via the SCSI card 203 and PCI bus 214 in accordance with a command from the CPU 201. Image data stored in a server connected to the LAN 213 or image data on the Internet is transferred to the main memory 202 via the NIC 204
15 and PCI bus 214 in accordance with a command from the CPU 201. The image data held in the main memory 202 is transferred to the graphic accelerator card 206 via the PCI bus 214 in accordance with a command from the CPU 201. The graphic accelerator card 206 digital-to-analog
20 (D/A) converts the image data if necessary, and then sends the image data to the color monitor 207 via a display cable. Hence, an image corresponding to the image data is displayed on the color monitor 207.

Upon receiving an instruction for printing an
25 image held in the main memory 202 by the color printer 209 (print command) from the user at the keyboard 211 or

mouse 212, the CPU 201 transfers color gamut information of a given color monitor and that of a given color printer from the HDD 205 to the main memory 202, and then transfers the two pieces of color gamut information

5   to the color signal converter 208. Image data held in the main memory 202 is transferred to the color signal converter 208 via the PCI bus 214 in accordance with a command from the CPU 201. The color signal converter 208 performs color signal conversion of the input image data,

10   and sends the image data as the conversion result to the color printer 209. The color printer 209 then prints an image corresponding to the image data on a recording sheet.

The user selects the printer model, the type of

15   recording sheet, and the monitor model used in printing in advance upon inputting a print command. Based on this selection information, the CPU 201 selects one of a plurality of pieces of color gamut information held in the HDD 205.

20   [Color Signal Converter]

Fig. 2 is a block diagram showing the arrangement of the color signal converter 208. In this embodiment, a case will be exemplified below wherein gamut mapping is done in the Lab color space.

25   The color signal converter 208 converts an Lab signal in a monitor color gamut (to be referred to as a

- 15 -

"monitor gamut" hereinafter) into that in a printer
color gamut (to be referred to as a "printer gamut"
hereinafter). The color signal converter 208 receives an
Lab signal of image data held in the main memory 202,
5   i.e., a color signal in the monitor gamut as a
conversion source, via a terminal 109. An output image
to the printer, i.e., a color signal in the desired
printer gamut, is output from a terminal 110.

The converter 208 receives printer gamut
10   information from a terminal 111, and monitor gamut
information from a terminal 112. The monitor gamut
information is stored in a storage unit 107, and the
printer gamut information in a storage unit 108.

Reference numeral 102 denotes a color signal
15   separation unit for separating an input Lab signal into
a lightness component L and chromaticity components a
and b, and outputting an L signal as the lightness
component to a lightness compression unit 103 and an ab
signal as chromaticity components to a saturation
20   compression unit 104. The lightness compression unit 103
compresses lightness of the input L signal in accordance
with the input/output relationship determined based on
lightness range information extracted from the monitor
gamut information and printer gamut information, and a
25   predetermined compression relationship, and outputs an L
signal as a compression result to a color signal mixing

unit 105. The saturation compression unit 104 compresses

saturation of the input ab signal in accordance with the

input/output relationship determined based on saturation

range information extracted from the monitor gamut

5   information and printer gamut information, and a

predetermined compression relationship, and outputs an

ab signal as a compression result to the color signal

mixing unit 105.

The color signal mixing unit 105 mixes the input L

10   and ab signals and outputs an Lab signal to a gamut

inspection unit 106. The gamut inspection unit checks

whether or not the input Lab signal lies within the

printer gamut. If the input Lab signal lies within the

printer gamut, the unit 106 outputs the input Lab

15   signal; if the input Lab signal lies outside the printer

gamut, it outputs an Lab signal within the printer gamut

that minimizes the color difference.

In the above arrangement, the color signal

converter 208 operates as follows. Prior to operation,

20   the converter 208 receives color gamut information of

the color monitor 207 and that of the color printer 209

in accordance with a command from the CPU 201, and these

pieces of information are respectively stored as monitor

gamut information and printer gamut information in the

25   storage units 107 and 108. After that, image data in

which color information is described by an Lab signal is

sent to the color signal converter 208 in the raster

scan order via the PCI bus 214. The color signal

converter 208 performs color signal conversion of an Lab

signal of each pixel in the image data by means of gamut

5   mapping, and sequentially sends the converted signal to

the color printer 209.

In this color signal conversion, the input Lab

signal is separated by the color signal separation unit

102 into L and ab signals, which undergo gamut mapping

10   in the individual circuits that construct the color

signal converter 208.

Lightness Compression Unit

The lightness compression unit 103 is controlled

by a function $f(\cdot)$ that defines the input/output

15   relationship. That is, Lin as an L signal input to the

lightness compression unit 103 and Lout as an L signal

to be output satisfy a relation Lout = f(Lin). $f(\cdot)$ is

defined using a piecewise function consisting of n-1

segments, and is controlled to meet the following

20   conditions:

carrier of $f(\cdot)$ is [Lmin_monitor, Lmax_monitor]

in carrier, $f(\cdot)$ is continuous at all points

f(Lmin_monitor) = Lmin_printer

f(Lmax_monitor) = Lmax_printer

25   f'(Lmin_monitor) = α, α: $0 \leq \alpha$

f'(Lmax_monitor) = β, β: $0 \leq \beta$

$f(mi) = mi$, $i: 0 \leq i \leq n - 2$, mi: Lmin_printer < mi < Lmax_printer

$f'(mi) = 1$, $i: 0 \leq i \leq n - 2$, mi: Lmin_printer < mi < Lmax_printer

5
$f'(x) \neq 0$, x: Lmin_monitor < x < Lmax_monitor

where Lmin_monitor: L value of black of monitor

Lmax_monitor: L value of white of monitor

Lmin_printer: L value of black of printer

Lmax_printer: L value of white of printer

10
α: constant for controlling compression ratio near brightest point of lightness compression

β: constant for controlling compression ratio near darkest point of lightness compression

Note that n is the number of knots or the knot index of

15
the piecewise function.

Constant α for controlling the compression ratio decreases with increasing difference between Lmin_monitor and Lmin_printer. That is, a higher compression ratio is set near the darkest point. On the

20
other hand, constant β for controlling the compression ratio decreases with increasing difference between Lmax_monitor and Lmax_printer. That is, a higher compression ratio is set near the brightest point. In the first embodiment, $f(\cdot)$ is implemented as a

25
C2-continuous spline function of third order, defined by,

e.g., five knots and four segments. Also, for example,
m1 = 40, m2 = 50, and m3 = 70.

Fig. 3 shows the input/output relationship of
lightness when Lmin_monitor = 0, Lmax_monitor = 100,

5   Lmin_printer = 20, and Lmax_printer = 90 in a given
printer output using the first embodiment.
Saturation Compression Unit

Fig. 4 is a block diagram showing the arrangement
of the saturation compression unit 104. The unit 104

10   receives an ab signal from a terminal 125, and outputs a
saturation-compressed ab signal from a terminal 126. The
unit 104 receives monitor gamut information from a
terminal 127, and printer gamut information from a
terminal 128.

15   A coordinate signal transform section 121
transforms an ab signal that expresses chromaticity by
an orthogonal coordinate system into an hc signal that
expresses chromaticity by a polar coordinate system.
Note that an h signal represents angle in the polar

20   coordinate system, i.e., hue, and a c signal represents
the distance from the origin in the polar coordinate
system, i.e., saturation. A color signal separation
section 122 separates the input hc signal into a hue
component h and saturation component c, and outputs an h

25   signal as a hue component to a coordinate signal
transform section 124 and saturation computing section

21

123, and a c signal as a saturation signal to the saturation computing section 123.

The saturation computing section 123 computes saturation to be output from the input c signal in accordance with the input/output relationship determined based on saturation range information at a hue defined by the h signal, which information is extracted from the monitor gamut information and printer gamut information, and a predetermined compression relationship. A c signal as a computation result is output to the coordinate signal transform section 124. The coordinate signal transform section 124 transforms the hc signal into an ab signal, and outputs the ab signal.

The saturation computing section 123 is controlled by a function g(·) that defines the input/output relationship. That is, a c signal cin input to the saturation computing section 123 and a c signal cout to be output satisfy cout = g(cin). g(·) is defined using a cubic function, and is controlled to satisfy the following conditions:

carrier of g(·) is [0, Cmax_monitor]

$g(0) = 0$

$g(Cmax\_monitor) = Cmax\_printer$

$g'(0) = 1$

$g'(Cmax\_monitor) = \gamma, \ \gamma: \gamma > 0$

$g'(x) \neq 0, \ x: 0 \leq x \leq Cmax\_monitor$

Cmax_monitor is computed from the h signal and monitor gamut information and is defined as a maximum saturation value of the monitor gamut at a hue defined by the h signal. Cmax_printer is computed from the h

5 signal and printer gamut information, and is defined as a maximum saturation value of the printer gamut at a hue defined by the h signal. Also, γ is a value for controlling the compression ratio of saturation compression near the maximum saturation, and is

10 automatically determined by the saturation computing section 123 based on the relationship between Cmax_monitor and Cmax_printer under a limitation that it satisfies the aforementioned conditions. Upon automatically setting the γ parameter, as

15 Cmax_monitor/Cmax_printer as the ratio between Cmax_monitor and Cmax_printer becomes larger, the value γ becomes smaller. That is, the compression ratio increases.

Fig. 5 shows the input/output relationship of

20 saturation in a given printer output using the first embodiment. Note that Cmax_monitor = 60.51, and Cmax_printer = 40.17.

In the first embodiment, the saturation range information is computed as described above, but may be

25 computed by another means. For example, as the saturation range information of the monitor gamut,

maximum saturation information of a hue defined by the h

signal may be computed by interpolating primary color

saturation information. With this scheme, the saturation

range information can be easily computed. Also, the

5   saturation range information of the printer gamut may be

arbitrarily determined in advance. With this scheme,

color of maximum saturation can be adjusted.

       According to the first embodiment, lightness

compression input/output characteristics obtained upon

10   gamut mapping for a plurality of types of paper

qualities such as a normal paper sheet, dedicated

recording paper sheet, and the like in a color monitor

of a given model and a color printer of another model

are superposed on each other, as shown in Fig. 6. That

15   is, middle lightness can be preserved independently of

paper qualities. On the other hand, the compression

ratio changes largely in correspondence with the

lightness range that allows color reproduction near the

brightest or darkest point.

20   According to the first embodiment, color

continuity can be maintained, and tones outside the

printer gamut can be reproduced. Furthermore, a

middle-lightness region (see Fig. 3) and low-saturation

region (see Fig. 5), as color gamuts to which the human

25   eye is sensitive and which are frequently included in a

photo image, can be reproduced with high precision.

Therefore, an input image whose colors fall outside the printer gamut can be faithfully reproduced by the printer.

Since the middle-lightness and low-saturation
5 regions can be reproduced with high precision, color reproducibilities for the middle-lightness and low-saturation regions can match for various types of recording sheets (recording media) having different color reproduction characteristics (color gamuts), as
10 shown in Fig. 6, and the tinctures of images printed on individual recording sheets can be matched.

Second Embodiment

A signal processing apparatus according tot he second embodiment of the present invention will be
15 explained below. The same reference numerals in the second embodiment denote the same parts as in the first embodiment, and a detailed description thereof will be omitted.

In the second embodiment, the operation of the
20 saturation compression unit 104 in the first embodiment is modified. The saturation computing section 123 in the saturation compression unit 104 is controlled by a function $g(\cdot)$ that defines the input/output relationship. That is, a c signal cin input to the saturation
25 computing section 123 and a c signal cout to be output satisfy cout = g(cin). $g(\cdot)$ is defined using a piecewise

function consisting of n-1 segments, and is controlled
to satisfy the following conditions:

   carrier of g(·) is [0, Cmax_monitor]

   g(0) = 0

5   g(Cmax_monitor) = Cmax_printer

   g'(0) = 1

   g'(Cmax_monitor) = γ, γ: γ > 0

   g(mi) = mi, i: 0 ≤ i ≤ n − 2, mi: 0 < mi <
Cmax_monitor

10   g'(mi) = 1, i: 0 ≤ i ≤ n − 2, mi: 0 < mi <
Cmax_monitor

   g'(x) ≠ 0, x: 0 ≤ x ≤ Cmax_monitor
Note that n is the number of knots of the piecewise
function.

15   Cmax_monitor is computed from the h signal and
monitor gamut information and is defined as a maximum
saturation value of the monitor gamut at a hue defined
by the h signal. Cmax_printer is computed from the h
signal and printer gamut information, and is defined as

20   a maximum saturation value of the printer gamut at a hue
defined by the h signal. Also, γ is a value for
controlling the compression ratio of saturation
compression near the maximum saturation, and is
automatically determined by the saturation computing

25   section 123 based on the relationship between
Cmax_monitor and Cmax_printer under a limitation that it

26

satisfies the aforementioned conditions. Upon

automatically setting the γ parameter, as

Cmax_monitor/Cmax_printer as the ratio between

Cmax_monitor and Cmax_printer becomes larger, the value γ

5   becomes smaller. That is, the compression ratio

increases.

In the second embodiment, $g(\cdot)$ is implemented as a

C2-continuous spline function of third order, which

consists of 2 segments. Also, for example, m1 = 1/2 ×

10   Cmax_monitor.

Fig. 7 shows the input/output relationship of

saturation in a given printer output using the second

embodiment. Note that Cmax_monitor = 60.51 and

Cmax_printer = 40.17.

15   Third Embodiment

A signal processing apparatus according to the

third embodiment of the present invention will be

described below. The same reference numerals in the

third embodiment denote the same parts as in the first

20   embodiment, and a detailed description thereof will be

omitted.

Fig. 8 is a block diagram showing the arrangement

of the color signal converter 208 according to the third

embodiment of the present invention.

25   An Lab signal of image data held in the main

memory 202, i.e., a color signal in the monitor gamut as

a conversion source, is input to the color signal
converter 208 that converts an Lab signal in the monitor
gamut into that in the printer gamut via the terminal
109. An output image to the printer, i.e., a color

5   signal in the desired printer gamut, is output from the
terminal 110.

       The converter 208 receives printer gamut
information from the terminal 111, and monitor gamut
information from the terminal 112. The monitor gamut

10   information is stored in the storage unit 107, and the
printer gamut information in the storage unit 108. A
storage unit 312 stores information as lightness and
saturation compression results with respect to the
monitor gamut (to be referred to as "gamut compression

15   information" hereinafter).

       A multiplexer (MUX) 302 selects a signal input
from the storage unit 107 or the terminal 109 on the
basis of a selection signal input from the CPU 201 via a
terminal 313, and outputs the selected signal to the

20   color signal separation unit 102. Since the processes in
the color signal separation unit 102, lightness
compression unit 103, saturation compression unit 104,
and color signal mixing unit 105 are the same as those
that have been explained in the first embodiment using

25   Fig. 2, a detailed description thereof will be omitted.

An Lab signal output from the color signal mixing unit 105 is input to a demultiplexer (DMUX) 307, and is output to the storage unit 312 or a lightness adjustment unit 308 in accordance with a selection signal from the

5   CPU 201. The lightness adjustment unit 308 converts an L signal in accordance with the input/output relationship determined on the basis of the input Lab signal, printer gamut information, and gamut compression information stored in the storage unit 312, and outputs an Lab

10   signal as the conversion result to the aforementioned gamut inspection unit 106.

In the aforementioned arrangement, the color signal converter 208 operates as follows. Prior to operation, the converter 208 receives color gamut

15   information of the color monitor and that of the color printer in accordance with a command from the CPU 201, and these pieces of information are respectively stored as monitor gamut information and printer gamut information in the storage units 107 and 108. The color

20   signal converter 208 then generates gamut compression information as monitor gamut information that has undergone lightness and saturation compressions, and stores it in the storage unit 312. In this process, the MUX 302 selects a signal input from the storage unit 107,

25   and the DMUX 307 selects an output to the storage unit 312.

Upon completion of the process, the color signal converter 208 performs color signal conversion that gamut-maps an input Lab signal in the monitor gamut. In this process, the MUX 302 selects a signal input from

5   the terminal 109, and the DMUX 307 selects an output to the lightness adjustment unit 306.

Upon completion of the above operations, image data in which color information is described by an Lab signal is sent to the color signal converter 208 in the

10   raster scan order via the PCI bus 214. The color signal converter 208 performs color signal conversion of an Lab signal of each pixel in the image data by means of gamut mapping, and sequentially sends the converted signal to the printer. Hence, image data in which color

15   information is described by an Lab signal is sent to the color signal converter 208 in the raster scan order via the PCI bus 214. The color signal converter 208 performs color signal conversion of an Lab signal of each pixel in the image data by means of gamut mapping, and

20   sequentially sends the converted signal to the color printer 209.

Lightness Adjustment Unit

The lightness adjustment unit 308 extracts a information and b information from the input Lab signal,

25   and extracts a lightness maximum value Lmax_printer_ab and lightness minimum value Lmin_printer_ab, which have

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the same values as the extracted a information and b

information in a printer gamut, from the extracted a

information and b information, and the printer gamut

information. Subsequently, the unit 308 extracts a

5   lightness maximum value Lmax_compressed_ab and lightness

minimum value Lmin_compressed_ab, which have the same

values as the extracted a information and b information

in a monitor gamut that have undergone lightness and

saturation compressions (to be also referred to as a

10   "compressed gamut" hereinafter), from the extracted a

information and b information, and the gamut compression

information. The unit 308 computes lightness information

Lout from these pieces of extracted information, and L

information Lin of the input Lab signal in the following

15   procedure.

If at least one of Lmax_printer_ab,

Lmin_printer_ab, Lmax_compressed_ab, and

Lmin_compressed_ab is not extracted, Lout = Lin is set.

Otherwise, Lout is computed by:

20   Lout = $\alpha \cdot$ (Lin - Lmin_compressed_ab)

+ Lmin_printer_ab

for $\alpha = \dfrac{L\max\_printer\_ab - L\min\_printer\_ab}{L\max\_compressed\_ab - L\min\_compressed\_ab}$

The lightness adjustment unit 308 outputs an Lab

signal obtained by mixing the computed lightness

information Lout, and the a information and b information of the input Lab signal.

According to the third embodiment, gamut mapping with higher precision than the first embodiment can be implemented. That is, since an actual printer gamut has a very complicated shape, conversion based on a compression ratio, which is set according to Cmax_printer in the first embodiment, cannot perfectly convert input image data into a printer gamut. By contrast, according to the third embodiment, since gamut mapping is done based on the gamut compression information as data after compression that pertains to an input image, higher-precision gamut mapping can be implemented.

Fourth Embodiment

A signal processing apparatus according to the fourth embodiment of the present invention will be described below. Note that the same reference numerals in the fourth embodiment denote the same parts as those in the first and third embodiments, and a detailed description thereof will be omitted.

In the fourth embodiment, the operation of the lightness adjustment unit 308 in the third embodiment is modified. The lightness adjustment unit 308 extracts a information and b information from the input Lab signal, and extracts a lightness maximum value Lmax_printer_ab

and lightness minimum value Lmin_printer_ab, which have

the same values as the extracted a information and b

information in a printer gamut, from the extracted a

information and b information, and the printer gamut

5   information. Subsequently, the unit 308 extracts a

lightness maximum value Lmax_compressed_ab and lightness

minimum value Lmin_compressed_ab, which have the same

values as the extracted a information and b information

in a monitor gamut that have undergone lightness and

10   saturation compressions (to be also referred to as a

"compressed gamut" hereinafter), from the extracted a

information and b information, and the gamut compression

information. The unit 308 computes lightness information

Lout from these pieces of extracted information, and L

15   information Lin of the input Lab signal in the following

procedure.

　　　If at least one of Lmax_printer_ab,

Lmin_printer_ab, Lmax_compressed_ab, and

Lmin_compressed_ab is not extracted, Lout = Lin is set.

20   　　　Otherwise, Lout is computed using a function h(·)

that defines the input/output relationship. That is,

Lout = h(Lin) is set. h(·) is defined using a piecewise

function consisting of n-1 segments, and is controlled

to satisfy the following conditions:

25   　　　carrier of h(·) is [Lmin_compressed_ab,

Lmax_compressed_ab]

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in carrier, $h(\cdot)$ is continuous at all points

$h(\text{Lmin\_compressed\_ab}) = \text{Lmin\_printer\_ab}$

$h(\text{Lmax\_compressed\_ab}) = \text{Lmax\_printer\_ab}$

$h'(\text{Lmin\_compressed\_ab}) = \alpha, \ \alpha: 0 < \alpha$

$h'(\text{Lmax\_compressed\_ab}) = \beta, \ \beta: 0 < \beta$

$h(mi) = ni, \ i: 0 \leq i \leq n - 2, \ mi:$

$\text{Lmin\_compressed\_ab} < mi < \text{Lmax\_compressed\_ab}, \ ni:$
$\text{Lmin\_printer\_ab} < ni < \text{Lmax\_printer\_ab}$

$h'(mi) = 1, \ i: 0 \leq i \leq n - 2, \ mi:$

$\text{Lmin\_compressed\_ab} < mi < \text{Lmax\_compressed\_ab}$

$h'(x) \neq 0, \ x: \text{Lmin\_compressed\_ab} \leq x \leq$
$\text{Lmax\_compressed\_ab}$

Note that n is the number of knots of the piecewise
function $h(\cdot)$.

Also α and β are parameters that give compression
ratios at the end point of the carrier, and are
automatically computed under a limitation that they
satisfy the aforementioned conditions. Also, mi and ni
are automatically computed under a limitation that they
satisfy the aforementioned conditions. The automatic
computation algorithm is devised so mi = ni as much as
possible. But since priority is given to preserving
grayscale information and satisfying the aforementioned
conditions, the relation mi = ni is not always
guaranteed. However, the algorithm is devised to
minimize the absolute value of a difference, $|h(\text{Lin})$

- Lin|, between the input and output at each point as much as possible.

In the fourth embodiment, $h(\cdot)$ is implemented as a C1-continuous spline function of third order, which is defined by three segments. Also, $m1 = 1/3 \times Cmax\_monitor$, and $m2 = 2/3 \times Cmax\_monitor$.

Figs. 9 and 10 show the input/output relationship of lightness at given chromaticity ab in a certain printer output that uses the fourth embodiment. Note that $Lmin\_compressed\_ab = 40$, $Lmax\_compressed\_ab = 68$, $Lmin\_printer\_ab = 45$, and $Lmax\_printer\_ab = 64$ in Fig. 9. Also, $Lmin\_compressed\_ab = 60$, $Lmax\_compressed\_ab = 84$, $Lmin\_printer\_ab = 46$, and $Lmax\_printer\_ab = 75$ in Fig. 10.

According to the fourth embodiment, since nonlinear conversion is used in lightness compression, reproducibility in a middle lightness region can be further improved. Especially, color reproducibility in a region like cyan in which monitor and printer gamuts do not have any similar relationship can be improved.

Fifth Embodiment

A signal processing apparatus according to the fifth embodiment of the present invention will be explained below. Note that the same reference numerals in the fifth embodiment denote the same parts as those

in the first, third, and fourth embodiments, and a
detailed description thereof will be omitted.

In the fifth embodiment, the arrangement of the
saturation compression unit 104 in the fourth embodiment
5   is modified. Fig. 11 is a block diagram showing the
arrangement of the color signal converter 208 of the
fourth embodiment, which is substantially the same as
that shown in Fig. 8, except that an L signal is input
to the saturation compression unit 104 together with an
10 ab signal.

Fig. 12 is a block diagram showing the arrangement
of the saturation compression unit 104 of the fifth
embodiment. Unlike the saturation compression unit 104
shown in Fig. 4, an L signal is input to the saturation
15 computing section 123 via a terminal 426.

The saturation computing section 123 computes
saturation to be output from the input c signal in
accordance with the input/output relationship, which is
defined by saturation range information at a hue
20 determined by the h signal and lightness determined by
the input L signal, which information is extracted from
monitor gamut information and printer gamut information,
and a predetermined compression relationship. A c signal
as a computation result is output to the coordinate
25 signal transform section 124. The coordinate signal

transform section 124 transforms an hc signal into an ab signal, and outputs the ab signal.

The operation of the saturation computing section 123 with the above arrangement will be explained below with reference to the flow chart shown in Fig. 13.

In step S1000, maximum saturation Cmax_printer of a printer gamut at hue h is computed from hue h and printer gamut information input to the saturation compression unit 104. In step S1001, maximum saturation Cmax_monitor of a monitor gamut at hue h is computed from hue h and monitor gamut information input to the saturation compression unit 104. In step S1002, a ratio Rmax = Cmax_printer/Cmax_monitor of saturation Cmax_printer to saturation Cmax_monitor is computed.

In step S1003, maximum saturation CL_monitor of the monitor gamut at hue h and lightness L is computed from hue h, lightness L, and printer gamut information input to the saturation compression unit 104. In step S1004, a ratio R = c/CL_monitor of saturation c input to the saturation compression unit 104 to maximum saturation CL_monitor is computed.

In step S1005, a saturation ratio Rnew = g(R/Rmax) is computed using a function g(·) that defines the input/output relationship of the saturation ratios. In step S1006, the product of the saturation ratio Rnew and maximum saturation CL_monitor is output as the

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computation result of the saturation computing section

123. Note that the function $g(\cdot)$ that defines the

input/output relationship of the saturation ratios is

defined using a cubic function in the fifth embodiment,

5 and is controlled as follows:

· carrier of $g(\cdot)$ is $[0, 1]$

$g(0) = 0$

$g(1) = Rmax$

$g'(0) = 1$

10 $g'(Rmax) = \gamma, \gamma: \gamma > 0$

$g'(x) \neq 0, x: 0 \leq x \leq 1$

Note that γ is a value that controls the

compression ratio of saturation compression near the

maximum saturation at a given hue and lightness, and is

15 automatically determined in units of combinations of hue

and saturation values by the saturation computing

section 123 on the basis of the relationship between

Cmax_monitor and Cmax_printer under a limitation that it

satisfies the aforementioned conditions. Upon

20 automatically setting the γ parameter, γ assumes a

smaller value as Cmax_monitor/Cmax_printer becomes

larger. That is, the compression ratio increases.

Note that the function $g(\cdot)$ that defines the

input/output relationship is implemented using a cubic

25 function, but it may be implemented using a piecewise

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function like in the second embodiment within the scope of the invention.

According to the fifth embodiment, color outside the printer gamut can be linearly compressed, and that

5　inside the printer gamut can be nonlinearly compressed while increasing the compression ratio for a high-saturation region. That is, since the gamut boundary of the monitor undergoes linear saturation compression, tone reproduction in the high-saturation

10　region can be improved. Hence, reproducibility can be improved in, e.g., a vivid color gradation pattern prevalently used in DTP or the like, and since middle and low saturation regions to which the human eye is sensitive can be reproduced with high precision, a photo

15　image and the like can be satisfactorily reproduced.

According to the fifth embodiment, saturation at the outermost portion of the monitor gamut is linearly compressed, and that inside the monitor gamut undergoes nonlinear compression while setting higher compression

20　ratio for a region with higher saturation. Hence, since tone reproduction in the high-saturation region at the gamut boundary of the monitor can be improved, reproducibility can be improved in, e.g., a vivid color gradation pattern prevalently used in DTP or the like.

25　On the other hand, since middle and low saturation regions to which the human eye is sensitive can be

reproduced with high precision, a photo image and the like can be satisfactorily reproduced.

Furthermore, according to the fifth embodiment, since saturation at the outermost portion of the monitor gamut is linearly compressed, an arrangement for mapping correction can be easily constructed when mapping correction of the color gamut is made after color signal mapping like in the ninth embodiment to be described later.

Sixth Embodiment

A signal processing apparatus according to the sixth embodiment of the present invention will be described below. Note that the same reference numerals in the sixth embodiment denote the same parts as those in the first embodiment, and a detailed description thereof will be omitted.

Fig. 14 is a block diagram showing the arrangement of the color signal converter 208 according to the sixth embodiment.

The color signal converter 208 for converting an Lab signal in a monitor gamut into that in a printer gamut receives an Lab signal of image data held in the main memory 202, i.e., a color signal in the monitor gamut as a conversion source, via the terminal 109. An output image to the printer, i.e., a color signal in the desired printer gamut, is output from the terminal 110.

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The converter 208 receives printer gamut information from the terminal 111, and monitor gamut information from the terminal 112. The monitor gamut information is stored in the storage unit 107, and the

5 printer gamut information is stored in the storage unit 108.

The color signal separation unit 102 separates an input Lab signal into lightness and chromaticity components, and outputs an L signal as the lightness

10 component to the lightness compression unit 103 and saturation compression unit 104, and an ab signal as chromaticity components to the saturation compression unit 104.

The saturation compression unit 104 compresses

15 saturation in accordance with the input/output relationship determined based on saturation range information extracted from the monitor gamut information and printer gamut information, and a predetermined compression relationship, and outputs an ab signal 513

20 as a compression result to the color lightness compression unit 103. Also, the saturation compression unit 104 obtains lightness information required for lightness compression from the monitor gamut information, and executes an information process. The unit 104

25 outputs the extracted saturation range information and

monitor lightness information to the lightness compression unit 103 as a signal 512.

The lightness compression unit 104 compresses lightness of the L signal in accordance with the input/output relationship, which is determined based on the monitor lightness information that has undergone the information process in the saturation compression unit 104 and the extracted saturation range information, and a predetermined compression relationship, mixes an L signal as its compression result and the ab signal 513 input from the saturation compression unit 104, and outputs the mixed signal as an Lab signal to the gamut inspection unit 106.

Saturation Compression Unit

Fig. 15 is a block diagram showing the arrangement of the saturation compression unit 104 of the sixth embodiment. Unlike the saturation compression unit 104 shown in Fig. 12, the saturation compression unit 104 of this embodiment comprises a lightness information computing section 525. The section 525 computes maximum and minimum lightness values of the monitor gamut at chromaticity ab from the L signal, ab signal, and monitor gamut information input to the saturation compression unit 104, and outputs them as the signal 512 from a terminal 529.

Lightness Compression Unit

The operation of the lightness compression unit
103 in the above arrangement will be explained below.
The lightness compression unit 103 computes maximum
lightness information Lmax_printer_ab and minimum

5 lightness information Lmin_printer_ab of the printer
gamut at chromaticity ab from the input ab signal and
printer gamut information. Then, the unit 103 sets
maximum lightness information and minimum lightness
information input thereto as Lmax_monitor_ab and

10 Lmin_monitor_ab, and computes parameters required for
lightness compression computations from these four
pieces of lightness information.

The lightness compression unit 103 computes a
signal Lout using the computed parameters, and a

15 function f(·) that defines the input/output relationship
between an L signal Lin which is input to the lightness
compression unit 103 and is to undergo lightness
compression, and an L signal Lout to be output. Note
that f(·) is defined using a piecewise function

20 consisting of n-1 segments, and is controlled to satisfy
the following conditions:
carrier of f(·) is [Lmin_monitor_ab,
Lmax_monitor_ab]
In carrier, f(·) is continuous at all points

25   f(Lmin_monitor_ab) = Lmin_printer_ab
f(Lmax_monitor_ab) = Lmax_printer_ab

$$f'(Lmin\_monitor\_ab) = \alpha, \; \alpha: \; 0 \leq \alpha$$

$$f'(Lmax\_monitor\_ab) = \beta, \; \beta: \; 0 \leq \beta$$

$$f(mi) = ni, \; i: \; 0 \leq i \leq n - 2, \; mi: \; Lmin\_monitor\_ab$$

< mi < Lmax_monitor_ab, ni: Lmin_printer_ab < ni <

Lmax_printer_ab

$$f'(x) \neq 0, \; x: \; Lmin\_monitor\_ab < x <$$

Lmax_monitor_ab

Note that n is the number of knots of the piecewise

function.

In the sixth embodiment, f(·) is implemented as a

C2-continuous spline function of third order, which is

defined by five segments. Note that the number n of

knots, the value mi at each knot, and compression ratios

α and β at the end point of the carrier are

automatically computed from four pieces of lightness

information, i.e., Lmin_monitor_ab, Lmax_monitor_ab,

Lmin_printer_ab, and Lmax_printer_ab. An automatic

parameter setting algorithm sets parameters which

possibly yield f(x) = x within the range that preserves

grayscale information and satisfies the above conditions.

An outline of the automatic setting algorithm for α and

β is as follows.

As for α, if Lmin_monitor_ab $\leq$ Lmin_printer_ab, as

the difference between Lmin_monitor_ab and

Lmin_printer_ab becomes larger, α decreases under the

constraint condition $0 \leq \alpha \leq 1$. That is, the compression ratio near the darkest point becomes higher.

On the other hand, if Lmin_monitor_ab > Lmin_printer_ab, as the difference between

5   Lmin_monitor_ab and Lmin_printer_ab becomes larger, α increases under the constraint condition $\alpha > 1$. That is, the expansion ratio near the darkest point becomes higher.

Likewise, as for β, if Lmin_monitor_ab $\geq$

10 Lmin_printer_ab, as the difference between Lmin_monitor_ab and Lmin_printer_ab becomes larger, β decreases under the constraint condition $0 \leq \beta \leq 1$. That is, the compression ratio near the brightest point becomes higher.

15 On the other hand, if Lmin_monitor_ab < Lmin_printer_ab, as the difference between Lmin_monitor_ab and Lmin_printer_ab becomes larger, β increases under the constraint condition $\beta > 1$. That is, the expansion ratio near the brightest point becomes

20 higher.

Seventh Embodiment

A signal processing apparatus according to the seventh embodiment of the present invention will be described below. Note that the same reference numerals

25 in the seventh embodiment denote the same parts as those

in the first, third, and fourth embodiments, and a detailed description thereof will be omitted.

In the seventh embodiment, the arrangement of the saturation compression unit 104 in the fourth embodiment is modified. Fig. 16 is a block diagram showing the arrangement of the color signal converter 208 of the seventh embodiment.

A saturation adjustment information input unit 618 is used by the user to input saturation adjustment information, and is constructed by, e.g., a control panel formed as a user interface image on the color monitor 207 by the CPU 201, keyboard 211 and/or mouse 212, and the like. Saturation adjustment information input by giving input and output values at respective knots is converted into a given data structure by the CPU 201, and is temporarily held in the main memory 202. The saturation adjustment information is then input to the saturation compression unit 104 in the color signal converter 208 via a terminal 617. Note that input of the saturation adjustment information is not mandatory.

Upon receiving a command for outputting an image held in the main memory 202 to the color printer 209, the CPU 201 checks the storage contents of the main memory 202 to determine the presence/absence of input of the saturation adjustment information, and sends the presence/absence information to the color signal

converter 208. When the saturation adjustment information is input, the CPU 201 sends the saturation adjustment information held in the main memory 202 to the color signal converter 208 via the PCI bus 214 and

5 terminal 617.

The saturation compression unit 104 compresses saturation in accordance with the input/output relationship determined based on saturation range information extracted from the monitor gamut information

10 and printer gamut information, and a predetermined compression relationship, and outputs an ab signal as its compression result to the color signal mixing unit 105.

Note that the saturation adjustment information

15 input unit 618 in the above arrangement is implemented when the individual blocks in the arrangement shown in Fig. 2 operate in the predetermined order, as described above.

Saturation Compression Unit

20 Fig. 17 is a block diagram showing the arrangement of the saturation compression unit 104.

Referring to Fig. 17, a storage unit 625 stores saturation adjustment information input via a terminal 630, and outputs a saturation adjustment value

25 corresponding to an h signal as hue information input from the color signal separation section 122 to the

saturation computing section 123. The saturation
computing section 123 computes saturation to be output
based on the input c signal in accordance with the
input/output relationship, which is determined based on

5   saturation range information at a hue defined by the h
signal, which is extracted from monitor gamut
information and printer gamut information, and a
compression relationship controlled by the saturation
adjustment information, and outputs a c signal as its

10   computation result to the coordinate signal transform
section 124.

      The operation of the saturation computing section
123 in the above arrangement will be explained below.
The saturation computing section 123 is controlled by a

15   function $g(\cdot)$ that defines the input/output relationship,
and cout = g(cin) holds between an input c signal cin
and a c signal cout to be output. $g(\cdot)$ is defined using
a cubic function, and is controlled to satisfy the
following conditions:

20   carrier of $g(\cdot)$ is [0, Cmax_monitor]

        g(0) = 0

        g(Cmax_monitor) = Cmax_printer

        $g'(0) = \alpha$

        $g'(Cmax\_monitor) = \gamma, \gamma: \gamma > 0$

25        $g'(x) \neq 0, x: 0 \leq x \leq Cmax\_monitor$

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Note that α is defined by the output value of the storage unit 625, i.e., is the saturation adjustment value at the hue defined by the h signal. Cmax_monitor is computed from the h signal as a hue component and

5 monitor gamut information, and is defined as a maximum saturation value of the monitor gamut at the hue defined by the h signal. On the other hand, Cmax_printer is computed from the h signal as hue information and printer gamut information, and is defined as a maximum

10 saturation value of the printer gamut at the hue defined by the h signal.

γ is a value for controlling the compression ratio of saturation compression near the maximum saturation, and is automatically set by the saturation computing

15 section 123 on the basis of the relationship between Cmax_monitor and Cmax_printer under a limitation that it satisfies the aforementioned conditions. Upon automatically setting the γ parameter, as Cmax_monitor/Cmax_printer as the ratio between

20 Cmax_monitor and Cmax_printer becomes larger, the value γ becomes smaller. That is, the compression ratio increases.

Saturation Adjustment Information

The user inputs as saturation adjustment

25 information slope y at x = 0 of a saturation control function at one or a plurality of arbitrary hues. The

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storage unit 625 linearly interpolates saturation as a
function of hue angle, and generates saturation
adjustment information at all hues. This information is
formed as a set of hues and saturation adjustment values
5   α at the respective hues. The set information is held
as saturation adjustment information in the storage unit
625.

Inputting slope y at x = 0 of the saturation
control function at an arbitrary hue by the user as
10   saturation adjustment information amounts to computing
ideal saturation after gamut mapping at designated
saturation by multiplying original saturation by y, and
intuitive saturation adjustment is facilitated very much.
Eighth Embodiment
15   A signal processing apparatus according to the
eighth embodiment of the present invention will be
described below. Note that the same reference numerals
in the eighth embodiment denote the same parts as those
in the first, third, and fourth embodiments, and a
20   detailed description thereof will be omitted.

In the eighth embodiment, the arrangement of the
saturation compression unit 104 in the fourth embodiment
is modified. Fig. 18 is a block diagram showing the
arrangement of the color signal converter 208 of the
25   eighth embodiment.

A lightness adjustment information input unit 718 is used by the user to input lightness adjustment information, and is constructed by, e.g., a control panel formed as a user interface image on the color

5 monitor 207 by the CPU 201, keyboard 211 and/or mouse 212, and the like. Saturation adjustment information input by giving input and output values at respective knots is converted into a given data structure by the CPU 201, and is temporarily held in the main memory 202.

10 The lightness adjustment information is then input to the lightness compression unit 103 in the color signal converter 208 via a terminal 717. Note that input of the lightness adjustment information is not mandatory.

Upon receiving a command for outputting an image

15 held in the main memory 202 to the color printer 209, the CPU 201 checks the storage contents of the main memory 202 to determine the presence/absence of input of the lightness adjustment information, and sends the presence/absence information to the color signal

20 converter 208. When the lightness adjustment information is input, the CPU 201 sends the lightness adjustment information held in the main memory 202 to the color signal converter 208 via the PCI bus 214 and terminal 717.

25 The lightness compression unit 103 compresses lightness of the input L signal in accordance with the

input/output relationship determined based on lightness

range information extracted from the monitor gamut

information and printer gamut information, a

predetermined compression relationship, and the input

5   lightness adjustment information, and outputs an L

signal as its compression result to the color signal

mixing unit 105.

Lightness Compression Unit

      The lightness compression unit 103 is controlled

10   by a function $f(\cdot)$ that defines the input/output

relationship, and Lout = f(Lin) holds between an input L

signal Lin and an L signal Lout to be output. $f(\cdot)$ is

defined using a piecewise function consisting of n-1

segments, and is controlled to satisfy the following

15   conditions:

      carrier of $f(\cdot)$ is [Lmin_monitor, Lmax_monitor]

      in carrier, $f(\cdot)$ is continuous at all points

      f(Lmin_monitor) = Lmin_printer

      f(Lmax_monitor) = Lmax_printer

20   f'(Lmin_monitor) = α, α: $0 \leq \alpha$

      f'(Lmax_monitor) = β, β: $0 \leq \beta$

      f(mi) = ni, i: $0 \leq i \leq n - 2$, mi: Lmin_printer <

mi < Lmax_printer, ni: Lmin_printer < ni < Lmax_printer

      f'(mi) = γi, i: $0 \leq i \leq n - 2$, mi: Lmin_monitor <

25   mi < Lmax_monitor

      f'(x) $\neq$ 0, x: Lmin_monitor < x < Lmax_monitor

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Note that n is the number of knots of the piecewise

function, and is controlled by the input from the

lightness adjustment information input unit 718 in the

eighth embodiment.

5   Lmin_monitor is an L value held by black of the

monitor, Lmax_monitor is an L value held by white of the

monitor, Lmin_printer is an L value held by black of the

printer, and Lmax_printer is an L value held by white of

the printer. In this embodiment, $f(\cdot)$ is implemented by

10   a spline function of third order, which is at least

C1-continuous at each knot. Note that α, β, the number

n of knots, mi, ni, and γi are set by the input upon

inputting the lightness adjustment information. If at

least one of α and β is not input, the algorithm

15   automatically sets one or both of α and β. If no γi is

input, γi is automatically computed by the algorithm

based on C2 continuity at knot i.

When the user does not input any lightness

adjustment data, n = 5, mi = ni, and γi = 1 are set, α

20   and β are automatically set under the above conditions,

and these parameters are set in the function $f(\cdot)$.

In the automatic computation algorithm of α and β,

as the difference between Lmin_monitor and Lmin_printer

becomes larger, the value α becomes smaller. That is,

25   the compression ratio near the darkest point becomes

higher. On the other hand, as the difference between

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Lmax_monitor and Lmax_printer becomes larger, the value β becomes smaller. That is, the compression ratio near the brightest point becomes higher.

According to the aforementioned embodiments, in
5   gamut mapping, middle lightness is preserved, and color with very high or low lightness is compressed at a higher ratio. On the other hand, in gamut mapping, the saturation of color with lower saturation is preserved, and color with higher saturation is compressed at a
10   higher ratio. With such nonlinear mapping, output images having very similar perceptual colors can be obtained independently of different color reproducibilities due to different models of monitors and printers, or different color reproducibilities due to different color
15   reproduction characteristics of recording media.

The above embodiments have been explained in reference to the typical Lab color space. However, these embodiments are not limited to such specific color space, but may be applied to any other color spaces having
20   lightness and chromaticity such as an Luv color space, Munsell color space, and the like.

Furthermore, according to each of the above embodiments, lightness and chromaticity signals are separated and mapped, and mapping characteristics are
25   determined based on the maximum and minimum lightness values and maximum saturation value upon mapping, i.e.,

the arrangement is simple. Therefore, when mapping

correction of a color reproduction region is made after

color signal mapping like in the ninth embodiment to be

described later, an arrangement for implementing that

5   mapping correction can be easily constructed.

Moreover, according to each of the above

embodiments, since means for controlling each knot is

provided as adjustment means used when the input/output

characteristics of lightness mapping are implemented by

10   a piecewise function, it is easy for the user to control

mapping.

In addition, according to each of the above

embodiments, since means for controlling the slope of

the input/output characteristic curve when saturation is

15   zero is provided as adjustment means used when the

input/output characteristics of lightness mapping are

implemented by a piecewise function, it is easy for the

user to control mapping.

Ninth Embodiment

20   The ninth and tenth embodiments according to the

present invention will be described below. These

embodiment will exemplify conversion of a color signal

in an Lab color space as a second color space into that

in an RGB color space as a first color space, and

25   conversion of a color signal in an Lab color space as a

first color space into that in a CMY color space as a

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second color space. However, the present invention is not limited to such specific types of color spaces, and color signals can be converted in two ways among arbitrary color spaces such as XYZ, Luv, YIQ, HSB, HSL,

5 CMY, CMYK, sRGB, and the like.

An image processing apparatus according to the ninth embodiment of the present invention will be described below. Note that the same reference numerals in the ninth embodiment denote the same parts as those

10 in the first embodiment, and a detailed description thereof will be omitted.

[Color Signal Converter]

Fig. 20 is a block diagram showing the arrangement of the color signal converter 208.

15 Referring to Fig. 20, an LUT generator 1201 generates a look-up table (LUT) for converting image data RGB into CMYK when its units operate in the designated procedure. An LUT generated by the LUT generator 1201 is stored in a RAM 1202. An interpolator

20 1203 computes CMYK data to be output based on RGB data input from a terminal 1212 by interpolation using the LUT stored in the RAM 1202, and outputs the CMYK data to a terminal 1213. Note that RGB image data held in the main memory 202 is input from the terminal 1212 in a

25 raster scan order. The CMYK data output from the terminal 1213 is sent to the color printer 209.

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Arrangement of LUT Generator

The arrangement of the LUT generator 1201 will be described in detail below.

A printer gamut storage unit 1205 stores printer
gamut information input from a terminal 1210, and a
monitor gamut storage unit 1204 stores monitor gamut
information input from a terminal 1211. A gamut mapping
unit 1206 compresses and maps the monitor gamut with
reference to the printer gamut information and monitor
gamut information. A compression & mapping result of the
monitor gamut that is processed by the gamut mapping
unit 1206 will be referred to as an "intermediate mapped
gamut" hereinafter. A gamut storage unit 1207 stores
intermediate mapped gamut information. A gamut
enlargement correction unit 1208 maps the intermediate
mapped gamut in a printer gamut with reference to the
intermediate mapped gamut information and printer gamut
information. A mapping result of the gamut enlargement
correction unit 1208 will be referred to as a "mapped
gamut" hereinafter. An LUT generation unit 1209
generates an LUT used to convert RGB data into CMYK data
with reference to the correspondence between the monitor
and mapped gamuts, RGB data that can produce a
predetermined color on the monitor, and CMYK data that
can produce the predetermined color on the printer.

Generation of LUT

Generation of an LUT will be explained below. A

case will be exemplified below wherein an L*a*b* color

space is used as a uniform colorimetric system.

The color signal converter 208 receives color

5   gamut information corresponding to the color monitor 207

and that corresponding to the color printer 209 in

accordance with a command from the CPU 201. When the two

pieces of color gamut information are respectively

stored in the monitor and printer gamut storage units

10   1204 and 1205, and transmission of the two pieces of

color gamut information is complete, the CPU 201

commands to start initialization for color signal

conversion. Upon receiving this command, in the color

signal converter 208, the gamut mapping unit 1206 is

15   launched to compress and map the monitor gamut in an

intermediate mapped gamut in the uniform colorimetric

system. In this operation, the aforementioned scheme for

nonlinearly compressing lightness and saturation, or the

like is used.

20   Figs. 21 to 23 are graphs for explaining gamut

mapping in the ninth embodiment. Fig. 21 is a graph

showing a monitor gamut for green hues. Fig. 22 is a

graph showing printer and monitor gamuts for green hues,

in which a printer gamut is indicated by the solid curve,

25   and a monitor gamut is indicated by the one-dashed chain

curve. Fig. 23 is a graph showing an intermediate mapped

gamut and printer gamut for green hues, in which an intermediate mapped is indicated by the solid curve, and a printer gamut is indicated by the one-dashed chain curve.

5   The gamut mapping unit 1206 nonlinearly compresses the lightness component of the monitor gamut, and nonlinearly compresses the saturation value of a chromaticity component at a predetermined hue. With this operation, the monitor gamut shown in Fig. 21 is mapped

10   to the intermediate mapped gamut shown in Fig. 23. Upon completion of the process of the gamut mapping unit 1206, the intermediate mapped gamut information as the gamut mapping result is stored in the gamut storage unit 1207, and the gamut enlargement correction unit 1208 is then

15   launched.

The gamut enlargement correction unit 1208 maps the intermediate mapped gamut in a printer gamut with reference to the intermediate gamut information and printer gamut information on the basis of an algorithm

20   (to be described later). The LUT generation unit 1209 generates an LUT for converting RGB data into CMYK data with reference to the mapped gamut as the mapping result of the gamut enlargement correction unit 1208, and writes the LUT in the RAM 1202. Upon completion of a

25   series of operations above, the color signal converter 208 informs the CPU 201 of the end of initialization.

Gamut Enlargement Correction Unit

Mapping in the gamut enlargement correction unit 1208 will be described below with reference to the flow chart in Fig. 24 and the graph in Fig. 25.

In step S601, color C to be mapped is set. In step S602, boundary color Bp of the printer gamut at the same lightness and hue as those of setting color C is computed. In step S603, boundary color Bi of the intermediate mapped gamut at the same lightness and hue as those of setting color C is computed. These colors C, Bp, and Bi have a relationship, as shown in the graph in Fig. 25. Subsequently, in step S604 saturation of color C is converted on the basis of the relationship among saturation values of colors Bp and Bi, and setting color C. If c_{org} represents saturation of color C, c_p that of color Bp, c_i that of color Bi, and c_{mod} converted saturation, this conversion is implemented by an input/output function $f(\cdot)$:

$$c_{mod} = f(c_{org}) \qquad\qquad \ldots(1)$$

Note that the input/output function $f(\cdot)$ is defined using a C2-continuous spline function of third order, and the following conditions are satisfied:

carrier of $f(\cdot)$ is $[0, c_i]$

$f(0) = 0$

$f(c_u) = c_p$

$f(0) = 1$

$$f(c_i) = \gamma, \; \gamma: \gamma > 1$$

$$f(x) \neq 0, \; x: 0 \leq x \leq c_i$$

γ is a parameter that controls an enlargement factor of saturation correction near maximum saturation, and is automatically determined by the gamut enlargement correction unit 1208 based on the relationship between saturation c_p of color Bp and saturation c_i of color Bi. Upon automatically setting the γ parameter, as the ratio c_p/c_i of saturation c_p to saturation c_i increases, the value γ increases. That is, the enlargement factor increases.

Fig. 26 shows an example of the input/output function $f(\cdot)$ used by the algorithm of the gamut enlargement correction unit 1208 for color C. When saturation correction is implemented by a smooth input/output function shown in Fig. 26, grayscale information can be preserved, and generation of pseudo edges can be prevented.

The aforementioned mapping is done for all colors that require gamut mapping.

Fig. 27 is a graph showing the gamut mapping result by the gamut enlargement correction unit 1208. Fig. 27 shows the gamut mapping result for green hues, i.e., the way the monitor gamut shown in Fig. 21 is mapped.

As described above, according to the ninth embodiment, gamut mapping can be made while fully utilizing the color gamut of an output device. Hence, upon outputting an image whose color gamut has been converted by gamut mapping of the ninth embodiment, a vivid image with high contrast can be obtained while fully using color reproduction performance of the output device. Furthermore, upon mapping that enlarges the gamut obtained by gamut mapping of the ninth embodiment, since an abrupt variation of change rate upon changes in color is prevented in advance, grayscale information of an output image can be preserved, and pseudo edges can be prevented from being generated, thus reproducing a preferred image.

Tenth Embodiment

An image processing apparatus according to the tenth embodiment of the present invention will be described below. Note that the same reference numerals in the tenth embodiment denote the same parts as those in the first and ninth embodiments, and a detailed description thereof will be omitted.

In the tenth embodiment, the arrangement and operation of the color signal converter 208 in the ninth embodiment shown in Fig. 20 are modified. Only modified portions will be explained below.

When gamut mapping from a monitor gamut to a
printer gamut uses the entire printer gamut, high
contrast can be obtained, but monitor and print images
may often appear largely differently due to the

5   difference between their color gamuts. This problem
poses a perceptual problem especially in image formation
of a photo image and the like.

Fig. 29 is a graph that compares monitor and
printer gamuts for cyan hues, in which a printer gamut

10   is indicated by the solid curve, and a monitor gamut is
indicated by the one-dashed chain curve. As can be seen
from Fig. 29, the printer gamut in a low-lightness range
is very broader than the monitor gamut. When the entire
printer gamut is used without considering such color

15   gamut difference, the aforementioned problem is posed.
In other words, the printer gamut used must be limited
to avoid this problem.

Fig. 28 is a block diagram showing the arrangement
of the color signal converter 208 of the tenth

20   embodiment. An upper-limit color reproductive range
computing unit 1008 computes an upper-limit color
reproductive range that indicates the upper limit of the
printer gamut used to limit use of the printer gamut, so
as to avoid the aforementioned problem. An upper-limit

25   color reproductive range storage unit 1009 stores

computed upper-limit color reproductive range information.

The gamut enlargement correction unit 1208 generates mapped gamut information obtained by mapping
5 an intermediate mapped gamut into a printer gamut with reference to intermediate mapped gamut information, printer gamut information, and upper-limit color reproductive range information.

Generation of LUT
10 The color signal converter 208 receives color gamut information corresponding to the color monitor 207 and that corresponding to the color printer 209 in accordance with a command from the CPU 201. When the two pieces of color gamut information are respectively
15 stored in the monitor and printer gamut storage units 1204 and 1205, and transmission of the two pieces of color gamut information is complete, the CPU 201 commands to start initialization for color signal conversion. Upon receiving this command, in the color
20 signal converter 208, the gamut mapping unit 1206 is launched to compress and map the monitor gamut in an intermediate mapped gamut in the uniform colorimetric system. In this operation, the aforementioned scheme for nonlinearly compressing lightness and saturation, or the
25 like is used.

Upon completion of the process of the gamut
mapping unit 1206, intermediate mapped gamut information
as the gamut mapping result is stored in the gamut
storage unit 1207, and the upper-limit color

5   reproductive range computing unit 1008 is then launched
to generate upper-limit color reproductive range
information. The generated information is stored in the
upper-limit color reproductive range storage unit 1009.
Note that the process of the upper-limit color

10 reproductive range computing unit 1008 will be described
in detail later.

After the upper-limit color reproductive range
information is stored in the storage unit 1009, the
gamut enlargement correction unit 1208 is launched. The

15 unit 1208 maps an intermediate mapped gamut into a
printer gamut based on an algorithm (to be described
later) with reference to the intermediate mapped gamut
information, printer gamut information, and upper-limit
color reproductive range information. The LUT generation

20 unit 1209 generates an LUT for converting RGB data into
CMYK data with reference to a mapped gamut as a mapping
result of the gamut enlargement correction unit 1208,
and writes it in the RAM 1202. Upon completion of a
series of operations above, the color signal converter

25 208 informs the CPU 201 of the end of initialization.
Upper-limit Color Reproductive Range Computing Unit

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Fig. 30 is a flow chart showing the operation algorithm of the upper-limit color reproductive range computing unit 1008.

In step S1201, a gamut is generated by enlarging the monitor gamut to a predetermined magnification α in the direction of saturation. This gamut will be referred to as an "enlarged monitor gamut" hereinafter. Fig. 31 is a graph showing the relationship among these gamuts, and shows gamuts at $L^* \approx 50$ in the a^*b^* plane. The solid curve represents the printer gamut, the one-dashed chain curve the monitor gamut, and the broken curve the enlarged monitor gamut.

In step S1202, color coordinate positions where the enlarged monitor gamut and printer gamut intersect (color coordinate positions CP1 and CP2 in Fig. 31) are computed. Note that since a gamut is expressed in a three-dimensional space in practice, the intersection color coordinate position is expressed by a curve.

Subsequently, in step S1203 the presence/absence of abrupt change in gamut at each intersection color coordinate position is checked. In step S1204, a gamut limit boundary for the color coordinate position at which the abrupt change in gamut is detected is computed. For example, when an abrupt change in gamut is detected at, e.g., the color coordinate position CP1 shown in Fig. 31, a gamut limit boundary indicated by the

two-dashed chain curve in Fig. 32 is computed. Note that the gamut limit boundary is formed by a curved surface in practice, and that curved surface is defined by a B-spline curved surface or triangular patch/polygon.

5   With the aforementioned processes, the upper-limit color reproductive range is computed. Fig. 32 depicts the upper-limit color reproductive range, as indicated by a hatched region.

Gamut Enlargement Correction Unit

10   Fig. 33 is a flow chart for explaining the operation of the gamut enlargement correction unit 1208.

In step S1501, color C to be mapped is set. In step S1502, boundary Bp of the printer gamut at the same lightness and hue as those of setting color C is

15   computed. In step S1503, boundary Bi of the intermediate mapped gamut at the same lightness and hue as those of setting color C is computed. Furthermore, in step S1504 boundary Bsup of the upper-limit color reproductive range at the same lightness and hue as those of setting

20   color C is computed. Fig. 34 shows the relationship among these colors C, Bp, Bi, and Bsup. Subsequently, in step S1505 saturation of color C is converted on the basis of the saturation relationship among the colors Bp, Bi, and setting color C. If c_{org} represent

25   saturation of color C, c_p that of color Bp, c_i that of color Bi, c_{sup} that of color Bsup, and c_{mod} the converted

saturation, this conversion is implemented by an
input/output function $f(\cdot)$:

$$c_{mod} = f(c_{org})$$

$$c_{max} = \min[c_p,\ c_{sup}] \hspace{4cm} \ldots(2)$$

5 Note that the input/output function $f(\cdot)$ is
defined using a C2-continuous spline function of third
order, and the following conditions are satisfied:

carrier of $f(\cdot)$ is $[0,\ c_i]$

$$f(0) = 0$$

10 $$f(c_i) = c_{max}$$

$$f(0) = 1$$

$$f(c_i) = \gamma,\ \gamma\colon \gamma > 1$$

$$f(x) \neq 0,\ x\colon 0 \leq x \leq c_i$$

As described above, γ is a parameter that controls
15 the enlargement factor of saturation correction near
maximum saturation, and is automatically determined by
the gamut enlargement correction unit 1208 based on the
relationship between saturation c_{max} and saturation c_i of
color Bi. Upon automatically setting the γ parameter, as
20 the ratio c_{max}/c_i of saturation c_{max} to saturation c_i
increases, the value γ increases. That is, the
enlargement factor increases.

Fig. 35 shows an example of the input/output
function $f(\cdot)$ used by the algorithm of the gamut
25 enlargement correction unit 1208 for color C. When
saturation correction is implemented by a smooth

input/output function shown in Fig. 35, grayscale information can be preserved, and generation of pseudo edges can be prevented.

The aforementioned mapping is done for all colors that require gamut mapping.

As described above, according to the tenth embodiment, not only gamut mapping that fully utilizes the color gamut of an output device can be attained, but also a high contrast ratio can be obtained by limiting the printer gamut used. In addition, gamut mapping that can match perceptual colors of monitor and print images can be attained, and it is especially effective in image formation such as a photo image and the like.

When an abrupt change in gamut like the color coordinate position CP1 shown in Fig. 31 has taken place as a result of limitation of use of the printer gamut, pseudo edges may be generated in an image output using the mapped gamut. That is, when a gamut that originally changes smoothly suffers an abrupt change, high-frequency components are produced in an output image, thus generating pseudo edges. To prevent this, when the use of the printer gamut is limited as in the tenth embodiment, an abrupt change in saturation is prevented to avoid pseudo edges from being generated, thus implementing gamut mapping that can obtain a satisfactory image free from pseudo edges.

Eleventh Embodiment

Nonlinear gamut mapping that preserves saturation values of low- and middle-saturation ranges, as described in the above embodiments, is effective to

5   solve the aforementioned problem, output of a perceptually unpreferable image. However, since the monitor gamut shape is largely different from the printer gamut shape, the colors perceived do not often match even by nonlinear gamut mapping.

10   Differences between the monitor and printer gamut shapes will be briefly explained below. For example, as can be seen from the printer gamut (solid curve) and monitor gamut (one-dashed chain curve) for green hues shown in Fig. 22, the monitor and printer gamuts for

15   green hues are not similar to each other, and have considerably different shapes.

On the other hand, monitor and printer gamuts for red hues have relatively similar shapes, as indicated by the solid curve (monitor gamut) and broken curve

20   (printer gamut) in Fig. 52.

In order to improve perceptual color matching between monitor and printer images, gamut mapping that absorbs any difference between the monitor and printer gamut shapes is required. That is, the eleventh

25   embodiment to be described below satisfactorily aims at obtaining a high-quality output image by absorbing any

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difference between the monitor and printer gamut shapes. Note that the same reference numerals in the eleventh embodiment denote the same parts as those in the first and ninth embodiments, and a detailed description

5   thereof will be omitted.

[Color Signal Converter]

    Fig. 36 is a block diagram showing the arrangement of the color signal converter 208 of the eleventh embodiment.

10   The LUT generation unit 1201 receives a printer gamut from the terminal 1210, and a monitor gamut from the terminal 1211. The monitor gamut storage unit 1204 stores the input monitor gamut, and the printer gamut storage unit 1205 stores the input printer gamut. A

15   mapping parameter computing unit 2206 computes mapping parameters required in mapping (to be described later) with reference to the printer and monitor gamuts stored in the printer and monitor gamut storage units 1205 and 1204.

20   A gamut mapping unit 2207 maps the monitor gamut with reference to the mapping parameters computed by the mapping parameter computing unit 2206 and the monitor gamut information. The mapping result of the monitor gamut by the gamut mapping unit 2207 will be referred to

25   as a "first intermediate mapped gamut" hereinafter. A

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gamut storage unit 2208 stores the first intermediate mapped gamut information.

A gamut mapping unit 2209 maps only lightness for each color in the first intermediate mapped gamut with reference to the mapping parameters computed by the mapping parameter computing unit 2206 and the first intermediate mapped gamut information stored in the gamut storage unit 2208. In mapping by the gamut mapping unit 2209, chromaticity of each color is preserved. The mapping result of the first intermediate mapped gamut by the gamut mapping unit 2209 will be referred to as a "second intermediate mapped gamut" hereinafter. A gamut storage unit 2210 stores the second intermediate mapped gamut information.

A gamut correction unit 2211 maps the second intermediate mapped gamut into the printer gamut with reference to the second intermediate mapped gamut information and printer gamut information. The mapping result of the gamut correction unit 2211 will be referred to as a "mapped gamut" hereinafter.

The LUT generation unit 1209 generates an LUT for converting RGB data into CMYK data with reference to the correspondence between the monitor and mapped gamuts, RGB data that can obtain a predetermined color on the monitor, and CMYK data that can obtain the predetermined color on the printer.

Generation of LUT

Generation of the LUT will be explained in detail below. Note that a case will be exemplified wherein an L*a*b* color space is used as a uniform colorimetric system in a series of mapping operations in the eleventh embodiment.

The color signal converter 208 receives color gamut information corresponding to the color monitor 207 and that corresponding to the color printer 209 in accordance with a command from the CPU 201. The two pieces of color gamut information are respectively stored in the monitor and printer gamut storage units 1204 and 1205. Upon completion of transmission of the two pieces of color gamut information, the CPU 201 commands to start initialization for color signal conversion. Upon receiving this command, the LUT generation unit 201 operates as follows in the color signal converter 208.

The mapping parameter computing unit 2206 is launched to compute various parameters required for the operations of the gamut mapping units 2207 and 2209. Upon completion of computations of the parameters, the gamut mapping unit 2207 is launched to map the monitor gamut into the first intermediate mapped gamut in the uniform colorimetric system. In this operation, the

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aforementioned scheme for nonlinearly compressing
lightness and saturation, or the like is used.

Mapping by the gamut mapping unit 2207 will be
briefly described using the graphs in Figs. 19A, 22, and
5   37, although it will be explained in more detail later.

Fig. 19A shows a monitor gamut for green hues.
Fig. 22 shows a printer gamut for green hues, in which
the solid curve represents the printer gamut, and the
one-dashed chain curve represents the monitor gamut.
10 Fig. 37 shows a first intermediate mapped gamut for
green hues, in which the solid curve represents the
first intermediate mapped gamut, the one-dashed chain
curve represents the monitor gamut, and the broken curve
represents the printer gamut.

15 The gamut mapping unit 2207 separates each color
in the monitor gamut into lightness and chromaticity
components, and nonlinearly maps the lightness and
chromaticity components. With this operation, the
monitor gamut shown in Fig. 19A is mapped into the first
20 intermediate mapped gamut shown in Fig. 37.

Upon completion of mapping by the gamut mapping
unit 2207, the first intermediate mapped gamut
information is stored in the gamut storage unit 2208.
Then, the gamut mapping unit 2209 is launched to map the
25 first intermediate mapped gamut into the second
intermediate mapped gamut. This operation will be

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briefly described below using the graphs in Figs. 37 and 38, although it will be explained in more detail later. Fig. 38 is a graph showing the second intermediate mapped gamut for green hues, in which the solid curve

5   represents the second intermediate mapped gamut, and the one-dashed chain curve represents the first intermediate mapped gamut.

The gamut mapping unit 2209 separates each color in the first intermediate mapped gamut into lightness

10   and chromaticity components, and nonlinearly maps only the lightness component while maintaining the chromaticity component. Note that a lightness input/output function that implements mapping varies depending on chromaticity. With this mapping, the first

15   intermediate mapped gamut indicated by the solid curve in Fig. 37 is mapped into the second intermediate mapped gamut indicated by the solid curve in Fig. 38.

The gamut correction unit 2211 maps the second intermediate mapped gamut into the printer gamut with

20   reference to the second intermediate mapped gamut information and printer gamut information. The operation of the gamut correction unit 2211 will be briefly described using the graphs in Figs. 38 and 39, although it will be explained in more detail later. Fig. 39 is a

25   graph showing a mapped gamut for green hues, in which the solid curve represents the mapped gamut, and the

one-dashed chain curve represents the second intermediate mapped gamut.

The gamut correction unit 2211 separates each color in the second intermediate mapped gamut into lightness and chromaticity components, and nonlinearly maps a saturation component in the chromaticity component while maintaining the lightness component. With this mapping, the second intermediate mapped gamut shown in Fig. 38 is mapped into the mapped gamut shown in Fig. 39.

The LUT generation unit 1201 generates an LUT for converting RGB data into CMYK data with reference to the mapped gamut as the final mapping result, and writes it in the RAM 1202. Upon completion of a series of operations above, the color signal converter 208 informs the CPU 201 of the end of initialization.

Gamut Mapping Unit 2207

Nonlinear mapping of the lightness and chromaticity components in the gamut mapping unit 2207 is implemented as follows.

Nonlinear mapping of the lightness component is implemented by one input/output function independent from chromaticity. The input/output function in mapping is controlled to preserve middle lightness, and is controlled to decrease derivatives of the input/output function near highest lightness and lowest lightness,

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i.e., to set a high compression ratio. Furthermore, in order to prevent generation of pseudo edges or the like, the input/output function is controlled so that at least first derivatives are continuous (C1-continuous) at all

5   points. Fig. 40 shows an example of nonlinear mapping of lightness components implemented by the eleventh embodiment. Note that the control parameters of nonlinear mapping of lightness components are computed and set by the mapping parameter computing unit 2206.

10   Nonlinear mapping of the chromaticity component is implemented by further separating the chromaticity component into hue and saturation components, and nonlinearly mapping these hue and saturation components.

          Mapping of the saturation component will be
15   described below using the flow chart in Fig. 41. In step S1601, color M to be mapped is set. In step S1602, outer saturation compression ratio Rb at the hue of color M is obtained from the mapping parameter computing unit 2206. In step S1603, color Bm of a boundary of the monitor

20   gamut at the same lightness and hue as those of color M is computed. Fig. 42 is a graph showing the relationship between colors M and Bm. In Fig. 42, the solid curve represents the monitor gamut, and the broken curve represents the way outer saturation values of the

25   monitor gamut are mapped upon saturation mapping.

In step S1604, saturation Cm of color M and saturation Cbm of color Bm are computed to compute ratio R = Cm/Cbm. In step S1605, a saturation input/output function $g(\cdot)$ is obtained from the mapping parameter computing unit 2206 to map saturation. In step S1606, saturation is mapped based on computed or obtained parameters by:

$$Cm_{mapped} = Cbm \times g(R)$$

where Cm_{mapped} is the mapped saturation of color M.

Note that the saturation input/output function $g(\cdot)$ satisfies the following conditions:

carrier of $g(\cdot)$ is [0, 1]

$g(\cdot)$ is monotonous increase

$g(0) = 0$

$g(1) = Rb$

$g(\cdot)$ is at least C1-continuous

$g'(0) = 1$

$g'(1) = \gamma$, γ: $\gamma > 0$, γ is a constant for controlling compression, is set in units of hues, and changes in inverse proportion to Rb

$g'(x) \neq 0$, x: $0 \leq x \leq 1$

Fig. 43 is a graph showing the input/output function $g(\cdot)$ of saturation. That is, saturation is preserved as it is lower, and is compressed at a higher compression ratio as it is higher. Furthermore, since the input/output function is at least C1-continuous, the

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rate of change in saturation smoothly changes, and generation of pseudo edges and the like is suppressed.

Mapping of the hue component will be explained below using the flow chart in Fig. 44. In step S1901, color M to be mapped is set. In step S1902, a hue input/output function $h(\cdot)$ at the lightness of color M is obtained from the mapping parameter computing unit 2206. Note that the hue input/output function $h(\cdot)$ changes depending on lightness. In step S1903, hue is mapped by:

$$Hm_{mapped} = h(Hm)$$

where Hm is the hue of color M, and Hm_{mapped} is the mapped hue of color M.

Fig. 45 shows an example of the hue input/output function $f(\cdot)$. In Fig. 45, the hue angle is expressed in radians in which a positive b* axis direction in an a*b* chromaticity coordinate system is set at hue angle = 0 rad, and counterclockwise rotation is positive.

With the aforementioned mapping of the gamut mapping unit 2207, the monitor gamut shown in the graph in Fig. 19A is mapped into the first intermediate mapped gamut shown in the graph in Fig. 37. In Fig. 37, a gamut indicated by the solid curve is the first intermediate mapped gamut, that indicated by the one-dashed chain curve is the monitor gamut, and that indicated by the broken curve is the printer gamut.

Gamut Mapping Unit 2209

　　　　The operation of the gamut mapping unit 2209 will be explained below using the flow chart in Fig. 46.

　　　　In step S1201, color M to be mapped is set. Note that this color M is the one in the first intermediate mapped gamut, but does not represent the color in the monitor gamut. In step S1202, upper boundary B_U of the first intermediate mapped gamut at the same chromaticity as that of color M is computed. Fig. 47 shows the relationship between color M and upper boundary B_U. In step S1203, lower boundary B_L of the first intermediate mapped gamut at the same chromaticity as that of color M is computed. Fig. 47 also shows the relationship between color M and lower boundary B_L.

　　　　In step S1204, upper lightness correction value Ad_U at the same chromaticity as that of color M is obtained from the mapping parameter computing unit 2206. Upper lightness correction value Ad_U is a lightness correction value for upper boundary B_U, and is given as a real number which assumes a positive value in a direction in which lightness increases. Fig. 47 shows the relationship between upper lightness correction value Ad_U and upper boundary B_U. In Fig. 47, color $B_{Unmapped}$ indicates the mapping result of B_U by the gamut mapping unit 2209. Also, in Fig. 47, the solid curve represents the first intermediate mapped gamut, the one-dashed chain curve

the second intermediate mapped gamut, and the broken curve the printer gamut.

In step S1205, lower lightness correction value Ad_L at the same chromaticity as that of color M is obtained from the mapping parameter computing unit 2206. Lower lightness correction value Ad_L is a lightness correction value for lower boundary B_L, and is given as a real number which assumes a positive value in the direction in which lightness increases. Fig. 47 shows the relationship between lower lightness correction value Ad_L and lower boundary B_L. In Fig. 47, color $B_{Lmapped}$ indicates the mapping result of B_L by the gamut mapping unit 2209.

Subsequently, in step S1206 an input/output function $p(\cdot)$ that implements mapping for adjusting lightness is derived from the four parameters obtained in the above steps. Upon deriving the input/output function $p(\cdot)$, the following conditions must be satisfied:

carrier of $p(\cdot)$ is $[L_{BL}, L_{BU}]$

$p(\cdot)$ is monotonous increase in carrier

$p(L_{BL}) = L_{BLm}$

$p(L_{BU}) = L_{BUm}$

$p(\cdot)$ is at least C1-continuous

$p'(L_{BL}) = \alpha,\ \alpha: \alpha > 0,\ \alpha$ is a constant for controlling compression, and is set in units of

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chromaticity values in accordance with Ad_L. If Ad_L is positive, $\alpha \leq 1$; if Ad_L is negative, $\alpha \geq 1$.

$p'(L_{BU}) = \beta$, $\beta: \beta > 0$, β is a constant for controlling compression, and is set in units of

5   chromaticity values in accordance with Ad_U. If Ad_U is positive, $\beta \geq 1$; if Ad_U is negative, $\beta \leq 1$.

The input/output function $p(\cdot)$ is computed to satisfy the above conditions, and to preserve lightness in a middle portion of the carrier as much as possible

10   and to minimize change in lightness. In the eleventh embodiment, a C2-continuous spline function of third order is used as the input/output function $p(\cdot)$. A merit of using the C2-continuous spline function of third order is that the input/output function $p(\cdot)$ can be

15   uniquely determined from the conditions at the end point independently of the number of knots. Furthermore, since the input/output function is smoothly defined, a suppression effect of pseudo edges is expected.

Figs. 48A and 48B show examples of the

20   input/output function $p(\cdot)$ in the eleventh embodiment. In Fig. 48A, lightness in the middle portion of the carrier is nearly preserved, while it is compressed at a high ratio near high lightness and low lightness. Note that $L_{BL} = 40$, $L_{BLm} = 45$, $Ad_L = 5$, $L_{BU} = 68$, $L_{BUm} = 64$, and

25   $Ad_U = -4$.

In Fig. 48B, since lightness correction amounts Ad_L and Ad_U have large absolute values, a function of preserving lightness in the middle portion of the carrier is activated, but lightness is not perfectly preserved. That is, lightness is expanded largely near low lightness, and is largely compressed near high lightness. Note that $L_{BL} = 60$, $L_{BLm} = 46$, $Ad_L = -14$, $L_{BU} = 84$, $L_{BUm} = 75$, and $Ad_U = -9$. Colors having the same chromaticity as that of color M use an identical input/output function.

Finally, in step S1207 mapping for adjusting lightness, i.e., computing mapped lightness $Lm_{mapped} = p(Lm)$ based on lightness Lm of color M before mapping using the input/output function $p(\cdot)$ computed in step S1206 is made.

With the aforementioned mapping of the gamut mapping unit 2209, the first intermediate mapped gamut shown in the graph in Fig. 37 is mapped into the second intermediate mapped gamut shown in the graph in Fig. 38. Note that the solid curve represents the second intermediate mapped gamut, the one-dashed chain curve the first intermediate mapped gamut, and the broken curve the printer gamut in Fig. 38.

Gamut Correction Unit

The operation of the gamut correction unit 2211 will be described below with reference to the flow chart

in Fig. 49. The gamut correction unit 2211 has a

correction function of mapping a gamut in a reduced

scale in addition to a correction function of mapping a

gamut in an enlarged scale. The gamut correction unit

5   2211 sets color M to be mapped in step S2601. This color

M is the one in the second intermediate mapped gamut.

Boundary Bp of the printer gamut at the same lightness

and hue as those of color M is computed in step S2602,

and boundary Bi of the second intermediate mapped gamut

10   at the same lightness and hue as those of color M is

computed in step S2603. Furthermore, in step S2604

boundary Bsup of an upper-limit color reproductive range

at the same lightness and hue as those of color M is

computed. The upper-limit color reproductive range is a

15   limitation range that designates the use upper limit of

the printer gamut, and is computed and stored in advance

by the gamut correction unit 2211. Fig. 50 shows the

relationship among these colors M, Bp, Bi, and Bsup.

Note that the solid curve represents the second

20   intermediate gamut, the one-dashed chain curve the

upper-limit color reproductive range, and the broken

curve the printer gamut in Fig. 50.

Subsequently, in step S2605 an input/output

function q($\cdot$) that implements mapping for gamut

25   correction is derived from colors Bp, Bi, and Bsup

computed in the above steps. If Cp represents the

saturation of color Bp, Ci that of color Bi, Csup that
of color Bsup, and Cmax = min[Cp, Csup], the
input/output function $q(\cdot)$ is derived to satisfy:

carrier of $q(\cdot)$ is [0, Ci]

5            $q(0) = 0$

$q(Ci) = Cmax$

$q'(0) = 1$

$q'(Ci) = \gamma, \gamma: \gamma > 0$

$q'(x) \neq 0, x: 0 \leq x \leq Ci$

10   γ is a value for controlling the
enlargement/compression ratio of saturation correction
near the maximum saturation, and is automatically
determined. If Ci > Cp, $\gamma < 1$ and mapping by the
input/output function $q(\cdot)$ is compression. On the other
15 hand, if Ci $\leq$ Cp, $\gamma \geq 1$ and mapping by the input/output
function $q(\cdot)$ is expansion. In the eleventh embodiment,
a C2-continuous spline function of third order is used
as the input/output function $q(\cdot)$. A merit of using the
C2-continuous spline function of third order is that the
20 input/output function $q(\cdot)$ can be uniquely determined
from the conditions at the end point independently of
the number of knots. Furthermore, since the input/output
function is smoothly defined, a suppression effect of
pseudo edges is expected.

25   Figs. 51A and 51B show examples of the
input/output function $q(\cdot)$ in the eleventh embodiment.

Fig. 51A shows a case Ci ≤ Cp, and mapping is expansion.
Fig. 51B shows a case Ci > Cp, and mapping is
compression.

Finally, in step S2606 saturation of color M is
converted using the input/output function q(·) computed
in step S2605. If Corg represents the saturation of
color M, and Cmod the converted saturation, Cmod =
q(Corg).

With the aforementioned mapping of the gamut
correction unit 2211, the second intermediate mapped
gamut shown in the graph in Fig. 38 is mapped into the
mapped gamut shown in the graph in Fig. 39. In Fig. 39,
the solid curve represents the mapped gamut, the
one-dashed chain curve the second intermediate mapped
gamut, and the broken curve the printer gamut.

In this manner, according to the eleventh
embodiment, gamut mapping that absorbs any difference
between the monitor and printer gamut shapes can be
implemented. Furthermore, since an abrupt variation in
rate of change in color is prevented in advance in each
mapping, grayscale information of an output image is
preserved, generation of pseudo edges can be prevented,
and preferred image reproduction can be realized.

Also, a vivid output image with high contrast can
be reproduced at the upper limit of the performance of
an output device.

In each of the above embodiments, the monitor gamut is mapped into the printer gamut. Also, the techniques explained the above embodiments can be applied to gamut mapping in combinations of other

5   devices.

As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific

10 embodiments thereof except as defined in the appended claims.